

Natural Environment Research Council

Institute of Geological Sciences

Mineral Reconnaissance Programme Report

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No. 21

**A geochemical drainage
survey of the Fleet granitic
complex and its environs**

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**A geochemical drainage survey of
the Fleet granitic complex and its
environs**

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SUMMARY

A regional geochemical drainage reconnaissance programme was undertaken over 900 km² of south-west Scotland centred on the Fleet granitic complex. Rocks of Ordovician and Silurian age outcrop over the area, into which have been intruded the Fleet and Loch Doon plutons.

Multi-element analysis of stream sediments and heavy mineral concentrates shows a number of patterns of trace element distribution related to different lithologies and to mineralisation. Broad scale patterns exhibited by some elements denote compositional variations within the Lower Palaeozoic sediments and within the Fleet and Loch Doon plutons.

On the basis of the drainage data the sedimentary rocks have been divided into eight distinct geochemical units each characterised by different element distribution patterns. The Fleet and Loch Doon plutons have been sub-divided on the same basis.

Follow-up investigations of drainage anomalies led to the discovery of both structure-controlled and disseminated base metal mineralisation in the Penkiln drainage basin within the southern aureole of the Loch Doon granite. The distribution of Cu, Pb and Zn to the south and south-west of the Fleet granite suggests a zonation of vein mineralisation, with Cu prominent adjacent to the granite contact and Pb and Zn having a wider dispersion away from the granite. Other anomalies delineate a mineralised lineament that follows the regional strike of the Lower Palaeozoic sediments, south-east of the Fleet granite.

INTRODUCTION

The reconnaissance drainage survey described in this report covers an area of 900 km² within the Dumfries and Galloway region, centred on the Fleet Granite. The project was undertaken primarily to locate areas of mineral potential and additionally to provide comprehensive geochemical data of regional significance. Field sampling was first undertaken during 1970-1971 as part of a uranium reconnaissance programme sponsored by UKAEA and was continued during 1974-1975 for the Department of Industry mineral reconnaissance programme. The same procedures were employed as those used in a survey of the Criffel-Dalbeattie area to the east (Leake et al., 1978). The sample density for stream sediments was approximately 1 sample per 1.3 km² and for panned concentrates 1.5 km², but the density was greater in certain areas of interest. The survey area is included in the Wigtown (4), Kirkcudbright (5), Carrick (8) and Maxwelltown (9) sheets of the one-inch geological map of Scotland.

Geographical setting

The major part of the area is high ground, much of it over 300 m OD (Fig 1), and is given over to forestry or rough pasture. The highest hills are Cairnsmore of Fleet (711 m), Lamachan Hill (716 m) and the southern margin of the Rhinns of Kells (746 m).

The main rivers draining the area are the Cree, the Water of Fleet, and the Dee with its major tributary the Water of Ken, all of which flow south to south-west cross-cutting the structural grain of the Lower Palaeozoic rocks.

The upland areas are sparsely populated, the main centres of population (Newton Stewart, Kirkcudbright and Gatehouse of Fleet) being near the coast. Farming and forestry are the main occupations within the area.

GEOLOGY

General Geology

The area is situated within the Southern Uplands of Scotland, a region dominated by great thicknesses of Lower Palaeozoic turbidites with inliers of black shale, chert and volcanic rocks (Greig, 1971). The Fleet granite dominates the central part of the area (Fig. 2) and the southern part of the Loch Doon plutonic complex is exposed in the north.

The majority of the Lower Palaeozoic rocks consist of graded turbidites. North of the present area several different formations of greywacke, which persist for several tens of kilometres along strike and are separated by major strike faults, have been recognised on the basis of mineral composition (Floyd, 1975; Dawson et al., 1977). Recent work (J. D. Floyd, personal communication) has also led to the recognition of distinct greywacke formations between the Loch Doon and Fleet plutons.

The Fleet granite exhibits a decrease in biotite content towards its centre (Parslow, 1968) and three components have been distinguished. The outer contact of the pluton is sharp and the contact metamorphic aureole around most of the margin is restricted in width. Gravity data (Parslow and Randall, 1973) suggests that the contacts are less steep at depth than field evidence suggests and that a subsurface cupola exists to the south-west of the exposed mass. Aplite, pegmatite and quartz veins are seen throughout the granite but are most prominent in the contact zone (Blyth, 1954).

The rocks of the Loch Doon plutonic complex have been divided by Gardiner and Reynolds (1937) into three main rock types. The southern part of the intrusion is occupied by norite and diorite, grading northwards into an intermediate tonalite and finally into an adamellite in the central core of the complex.

Both of the plutonic complexes are considered to be of Lower Devonian age. The Fleet granite contains biotites with a K/A age of 386 ± 8 m.y. and a Rb/Sr age of 365 ± 11 m.y. (Kulp et al., 1960).

Structure

Most of the Lower Palaeozoic sedimentary rocks of the Southern Uplands young towards the north-west but they appear to form a series of units progressively older in the same direction, probably separated by major strike faults trending north-eastwards. Recently the structure of the Southern Uplands has been interpreted (McKerrow et al., 1977) in terms of a dynamic model involving sequential accretion of an imbricating sedimentary wedge onto the margin of the North American continent. This model explains the outcrop distribution within the Southern Uplands, as the younging of successive wedges towards the ocean and the younging of the sequence within each sediment wedge towards the continent is a diagnostic feature of recent examples of accretionary prisms that have been studied. In detailed sections across the northern part of the Southern Upland belt in a pipeline trench McKerrow found that reverse strike faults are predominant in imbricated zones of black shale and associated rocks.

Drift geology

During the period of maximum glaciation the whole area was covered by ice, which is evident from the occurrence of erratics on the summit of Merrick (843 m). Evidence of glacial activity is abundant, particularly in the aureole of the Doon granite, around Loch Dee and Glen Trool, where there are many corries, rock basins and ice-scraped bare rock surfaces. Striae on rock surfaces and the north-south alignment of drumlins on the lower ground gives evidence of a predominant movement of the ice originating from a centre in the Loch Doon area. Till covers much of the area, except in parts of the high ground in the Loch Dee and Cairnsmore of Fleet areas.

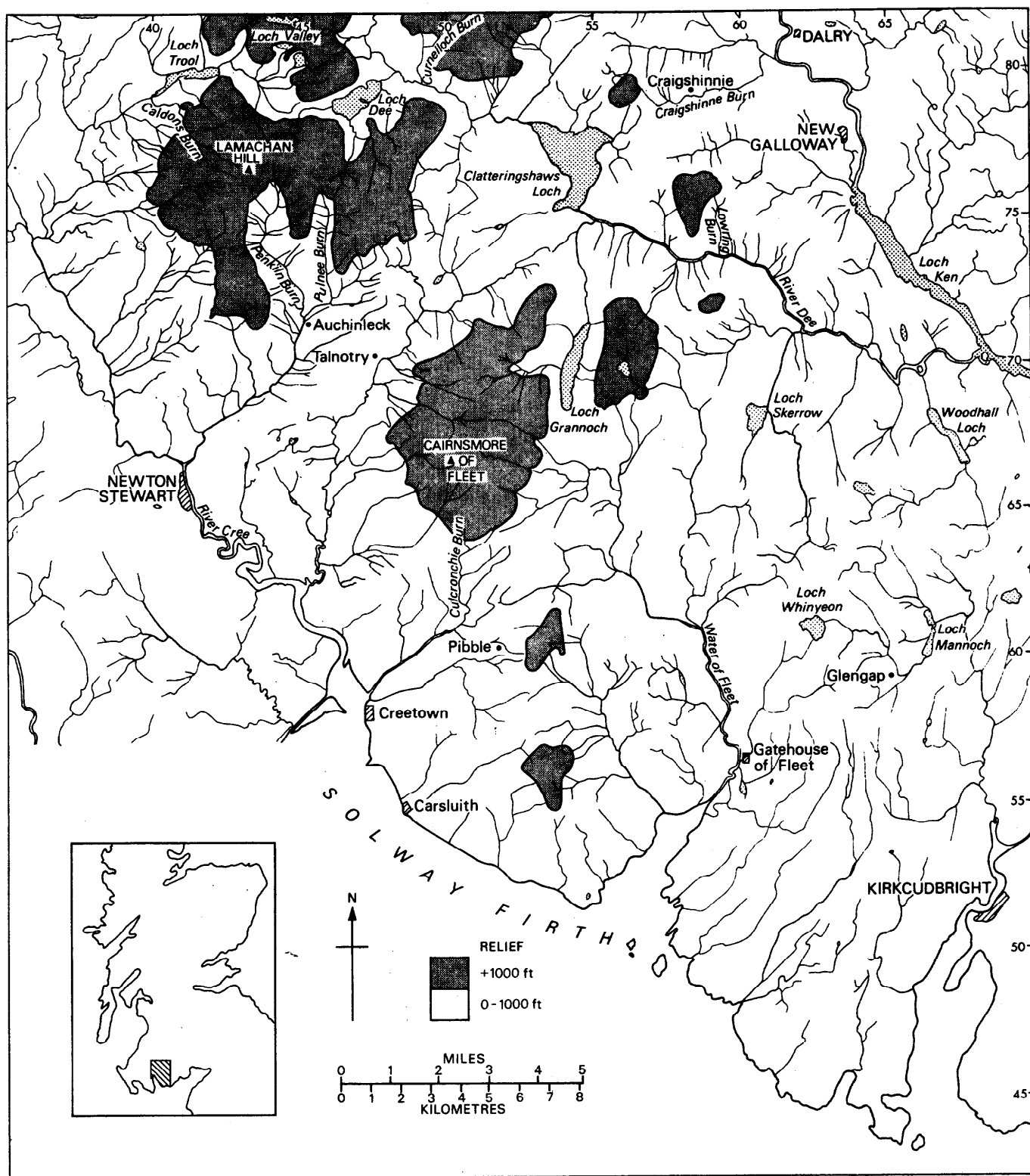


Fig. 1. Location of survey area.

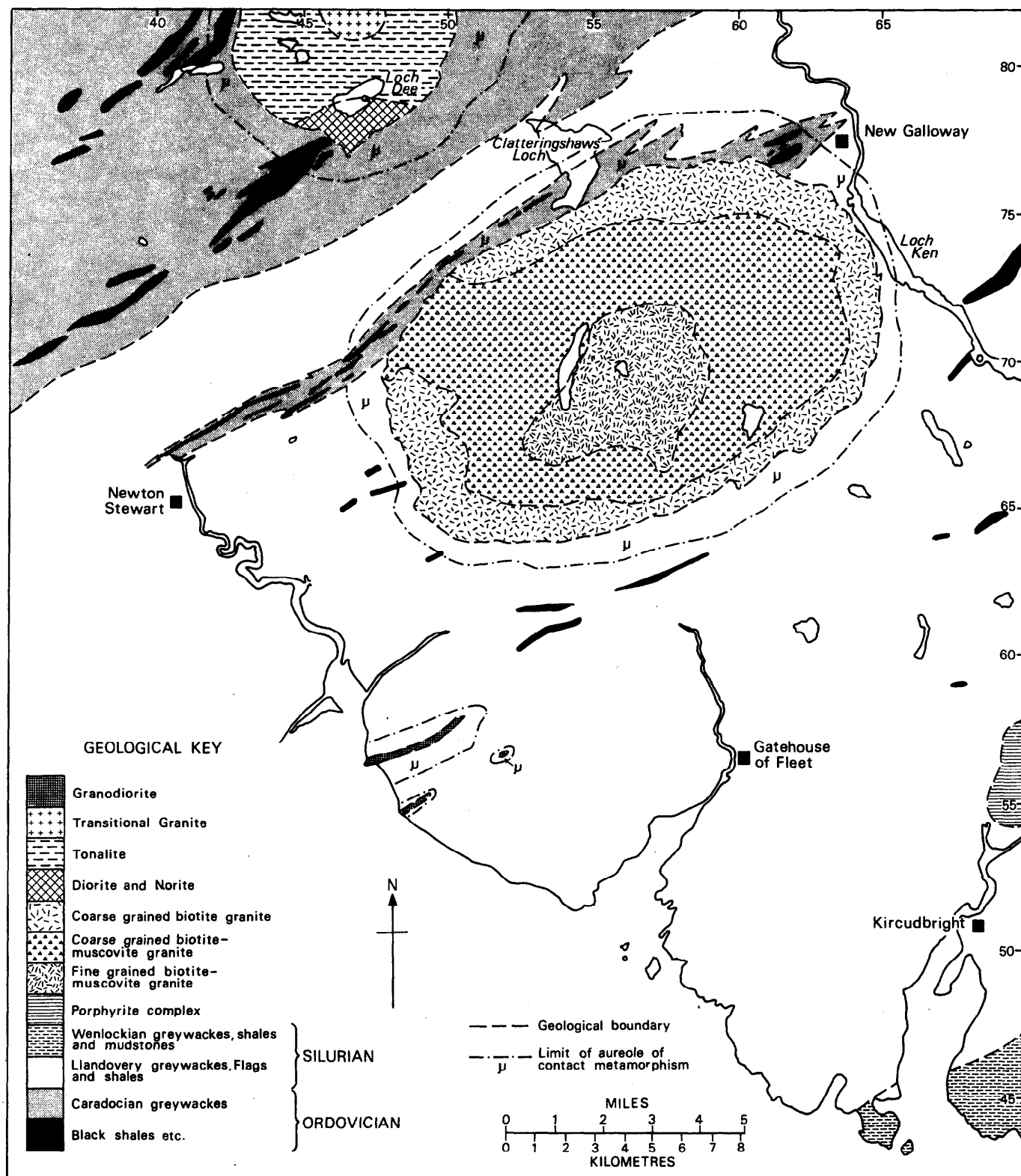


Fig. 2. Geological map of the area.

TABLE 1

Analytical, sampling and regional variance for stream sediments

Element	analytical variance (log10)	Total sampling + analytical variance (log10)	Regional variance (log10)	F ratio
Li	0.0005	0.0035	0.013	3.7
Be	0.0085	0.0110	0.030	3.7
B	0.0055	0.0156	0.055	2.8
MgO	0.0045	0.0101	0.084	8.3
K ₂ O	0.0050	0.0048	0.033	6.9
CaO	0.0020	0.0069	0.110	15.9
TiO ₂	0.0025	0.0064	0.020	3.1
V	0.0065	0.0147	0.088	6.0
Cr	0.0045	0.0095	0.044	4.6
Mn	0.0120	0.0580	0.168	2.9
Fe ₂ O ₃	0.0050	0.0210	0.041	2.0
Co	0.0065	0.0395	0.144	3.6
Ni	0.0085	0.0200	0.105	5.3
Cu	0.0075	0.0264	0.073	2.8
Zn	0.0050	0.0365	0.170	4.65
Ga	0.0015	0.0100	0.014	1.4
Rb	0.0010	0.0060	0.064	10.7
Sr	0.0075	0.0070	0.071	10.1
Y	0.0045	0.0170	0.016	0.92
Zr	0.0515	0.1275	0.124	0.97
Ba	0.0020	0.0205	0.018	0.9
La	0.0075	0.0470	0.064	1.36
Pb	0.0160	0.0390	0.162	4.15
U			0.081	

TABLE 2

Analytical, sampling and regional variance for panned concentrates

Element	Analytical variance (\log_{10})	Total sampling + analytical variance (\log_{10})	Regional variance (\log_{10})	F ratio
Ca	0.00015	0.0158	0.130	8.2
Ti	0.00009	0.0240	0.130	5.4
Mn	0.00009	0.042	0.101	4.2
Fe	0.00005	0.0158	0.100	6.3
Ni	0.00140	0.0200	0.078	3.9
Cu	0.00174	0.0470	0.338	7.2
Zn	0.00054	0.0070	0.080	11.4
Y		0.1060	0.260	2.4
Zr		0.1345	0.170	1.3
Nb		0.1365	0.470	3.4
Ba	0.00017	0.0095	0.027	2.8
Ce	0.04850	0.0425	0.049	1.2
Pb	0.00435	0.0750	0.394	5.3
Th		0.1955	0.270	1.4
U		0.0895	0.177	2.0

Along the Solway coast there is abundant evidence of post-glacial raised shorelines in the form of beach deposits. Three levels of terrace can be identified in the estuaries of the River Cree, River Dee and Water of Fleet at 7.5 m, 15 m and 30 m respectively, consisting of sand, gravels and clays. Most rivers and streams in the lower ground cut through older river terraces.

Previous mining activity

Galena and sphalerite were both mined during the last century on the south-west flank of the Cairnsmore of Fleet granite from Gatehouse of Fleet to north-west of Newton Stewart (Fig. 3). A full description of the mines is given by Wilson (1921).

The mineralisation occurs in veins, most of which trend west-north-west with some trending north-west or north-north-east. The veins are usually more productive where they traverse the greywackes than in the shales. The primary minerals are galena, sphalerite, pyrite, chalcopryrite and arsenopyrite, with calcite, dolomite, quartz and baryte as the main gangue minerals.

The veins were first worked for their lead and copper content although the working of zinc ores was the primary attraction later in their history. Apart from some of the old copper mines the Blackcraig mines were the first to be operated and for a number of years they yielded several hundred tons of lead per annum. Lead mining ceased in the area around 1882 but some mines were re-opened and worked during the First World War.

Nickel was worked on a trial basis at Talnotry mine situated on the west side of Palnure Burn. The Talnotry occurrence is of limited extent and differs from other deposits in the area in that the ore occurs at the base of a lens of diorite intruded into the Lower Palaeozoic turbidites. A geophysical VLF and magnetic survey in the mine area (Parker, 1977) failed to detect any extension of the mineralisation. The minerals present are pentlandite, chalcopryrite, pyrrhotite, niccolite and smaltite. Jones (1924) considered the deposit to be due to magmatic segregation but Gregory (1927) proposed that the diorite was altered by hydrothermal solutions which deposited the metal. Gardiner and Reynolds (1937) agreed that the ore was introduced but thought that the diorite alteration was due to contact metasomatism from the nearby granite. The source of the metals is not clear. A trial for arsenic minerals was made a few hundred metres south-east of the Talnotry mine, where arsenopyrite occurs in a vein at the margin of the granite.

The occurrence of mineral veins associated with the aureole of the Cairnsmore of Fleet granite suggest a Caledonian age for emplacement. Temple (1956) considered that the veins were later because of evidence from Blackcraig mine where a vein is younger than a west-north-west dolerite dyke which he considered Permo-Carboniferous in age. Age dating of galena by Moorbath (1962) on samples from Silver Ridge mine gives an age of 320 ± 80 my (Lower or Middle Carboniferous).

SAMPLE COLLECTION AND ANALYSIS

Stream sediments

Stream sediment samples were collected from all streams and tributaries at natural sediment traps beneath large boulders, at the upstream end of riffles and at the base of waterfalls. The sediment was screened through nylon-mesh sieves to minus 0.25 cm as described by Plant (1971). The material was later oven dried and sieved to give a minus 100 mesh BSS ($< 150 \mu\text{m}$) fraction for analysis.

The sediments were analysed for Li, Be, B, MgO, CaO, TiO_2 , V, Cr, Mn, Fe_2O_3 , Co, Ni, Cu, Ga, Rb, Sr, Y, Zr, Ba, La and Pb by a D-C arc direct-reading optical emission spectrometry technique developed by the Analytical and Ceramics Unit of IGS (Leake et al., 1978). Mo and Sn were determined by optical emission spectrography with plate evaluation by visual comparison (Tait and Coats, 1976). Zn was determined by atomic absorption spectrophotometry (AAS) using a nitric acid attack and U was determined by a delayed neutron activation technique (Ostle et al., 1972).

Panned concentrates

At sites where suitable amounts of sediment were available approximately 2-3 kg of material was collected by wet sieving to minus 0.25 cm and then panned down, using the classical gold panning technique, to constant volume to give about 20-30 g of concentrate. The material was then dried and sub-sampled by riffling to provide 12 g for analysis, the remainder being retained for mineralogical examination. The concentrates were then prepared for analysis as described by Leake and Aucott (1973).

The concentrates were analysed for Ca, Ti, Mn, Fe, Ni, Cu, Zn, Y, Nb, Sn, Sb, Ba, Ce, Pb, Th and U with a Philips PW1220C automatic X-ray fluorescence spectrometer fitted with a tungsten anode tube (Leake et al., 1978).

Analytical and sampling precision

The analytical and sampling precision of data collated from the south-west Scotland area has been described in detail in a report on the Criffel-Dalbeattie area (Leake et al., 1978). Tables 1 and 2 give the analytical, sampling and regional variance for stream sediments and panned concentrates within the Fleet area.

TABLE 3

Correlation matrix for stream sediment samples

Element	Correlation coefficients significant at > 99.95% confidence level						
	0.2 - 0.3	0.3 - 0.4	0.4 - 0.5	0.5 - 0.6	0.6 - 0.7	0.7 - 0.8	0.8 - 0.9
Li	Be -B Mg Mn Fe Co Zn -Zr Mo Ba U	K Ca Cu Rb Sr Pb	Ga				
Be	Li -Mg -V -Cr -Co -Ni U	-Fe	K Rb		La		
B	-Li Ti Cr Co Ga -Sr Y -La	Mg -K Ni Cu Zn -Rb -U	V Fe				
MgO	Li -Be -Sn	B -K Co Y Ba	Fe Zn Sr	Ca Cu -U	Ti Cr -Rb	V	Ni
K ₂ O	-Zr Mo Ba La	Li -B -Mg -Ti -V -Ni Ga	Be U	-Cr		Rb	
CaO	Ti V Cr Mn Fe Co Ga -Sn Pb	Li -Rb	Ni Ba	Mg			Sr
TiO ₂	Ba Ca Fe Zn -Mo	-K Cu Zr	Y -U	Cr -Rb	Mg V Ni		
V	-Be Ca Mn -Sn Ba	-K Zr -U	B Co Zn Y	Cr Cu	Ti Fe -Rb	Mg Ni	
Cr	-Be B Ca Cu -Ga Y -Mo -Pb	Zr	-U	-K Ti V Ni	Mg -Rb		
Mn	Li Ca V Ni Sr		Ga	Zn Ba Pb	Fe	Co	
Fe	Li Ca Ti -Sn	-Be -Rb Y	B Mg Cu Ba -La	Ni Zn Ga Pb	V Mn	Co	
Co	Li -Be B Ca Sr Y -Sn	Mg -Rb	V Cu Ba -La	Ni Ga	Zn Pb	Mn Fe	Mg
Ni	-Be Mn Sr -La	B -K Y -Sn Ba	Ca -U	Cr Fe Co Cu Zn	Ti -Rb	V	
Cu	Cr Ga -Rb	Li B Ti Y	Fe Co Pb	Mg V Ni Zn			
Zn	Li Ti -Rb -Sn -La	B Ga Ba Pb	Mg V	Mn Fe Cu	Co Ni		
Ga	B Ca -Cr Cu -La	K Zn	Li Mn Ba	Fe Co Pb			
Rb	-Cu -Zn -Y Mo Sn	Li -B -Ca -Fe -Co -Zr La	Be	-Ti U	-Mg -V Cr Ai	K	Ca
Sr	-B Mn Co Ni -Sn Pb	Li	Mg	Ba			
Y	B Cr Co -Rb La	Mg Fe Ni Cu Zr	Ti V				
Zr	-Li -K -Pb -U	Ti V Cr -Rb Y					
Mo	Li K -Ti -Cr Rb	U					
Sn	-Mg -Ca -V -Fe -Co -Zn Rb -Sr -Ba	-Ni					
Ba	Li K V -Sn Pb	Mg Ni Zn	Ca Fe Cu Ga	Mn Sr			
La	-B K -Ni -Zn -Ga Y	Rb -Pb	Fe -Co		Be		
Pb	Ca -Cr Sr -Zr Ba U	Li Zn -La	Cu	Mn Fe Ga Rb	Co		
U	Li Be -Zr Pb	-B -V Mo	K -Ti -Cr -Ni	Mn Fe Ga			

TABLE 4 Correlation matrix for panned concentrate samples

Correlation coefficients significant at >99.95% confidence level						
Element	0.25 - 0.30	0.30 - 0.40	0.40 - 0.50	0.50 - 0.60	0.60 - 0.70	>0.70
Ca		Mn Fe Ni Y	Ti Zr Nb			
Ti		Zn Ce	Ca Y		Mn Ni Zr	Fe
Mn		Ca Ni Zn Ce	Zr	Fe Y Nb	Ti	
Fe	Ba Ce	Ca	Y Nb	Mn	Zn Zr	Ti Ni
Ni	Y	Ca Mn Nb	Zr Ba		Ti Zn	Fe
Cu	Zr Sn	Zn				
Zn	Ba	Ti Mn Cu Y Pb	Zr		Fe Ni	
Y *	Ni	Ca Zn Ce	Ti Fe Nb	Mn Zr		
Zr *	Cu Pb	Sn Ce	Ca Mn Ni Zn	Y Nb	Ti Fe	
Nb *		Ni Ce	Ca Fe Y	Mn Zr		Ti
Sn	Cu	Zr Pb				
Sb						
Ba	Fe Zn		Ni			
Ce	Fe	Ti Mn Zr Nb Tn				
Pb	Zr	Zn Sn				
Th *		Ce				
U *						

Notes

Matrix based on data of 524 samples
 *Matrix based on data of 179 samples

DATA INTERPRETATION

Interpretative procedure

The methods used in presenting and interpreting the geochemical drainage data have previously been described for the Criffel-Dalbeattie area (Leake et al., 1978). Inter-element correlation coefficients, calculated from the log transformed data for both sample types, are shown in Tables 3 and 4. The geochemical data are plotted on geochemical maps which are presented, with descriptive text, in Appendix I.

Contamination

The main sources of contamination identified in drainage within the present area are human habitation, agricultural operations, forestry work (chiefly road building), old mining activity and crashed aircraft in the upland areas. Contamination with metallic rubbish is most obvious in the vicinity of human habitation or in relatively flat areas where farming predominates, such as the region between Gatehouse of Fleet and Kirkcudbright. In these areas it is generally not possible to avoid contaminated streams but the tin content of concentrate samples serves as a useful monitor in view of the absence of tin mineralisation in the area and the low level of tin in the common rock forming minerals. Lead is most frequently found with tin at contaminated sites while copper and zinc are much less common. Particular problems arise when ore minerals derived from mineralisation occur within contaminated samples as is the case for copper anomalies in the region between Gatehouse of Fleet and Kirkcudbright. In such cases anomalies originating from base-metal mineralisation can only be confirmed after mineralogical examination of concentrate samples. Generally copper and zinc anomalies, even when occurring in obviously contaminated samples, are screened for evidence of ore minerals whereas lead anomalies associated with high levels of tin without other evidence of mineralisation are rejected.

Contaminants have also been detected in samples from areas more remote from human habitation, generally in the form of flakes of non-magnetic alloy, granules of magnetic alloy or fragments of black ribbed alloy but in most cases no significant amounts of base metals have been detected in this material. Only in one sample from east of Clatteringshaws Loch is a contaminant (fragments of highly magnetic wire containing a significant amount of copper) known to be a major contributant to a base-metal anomaly. Fragments of light alloy probably derived from a nearby crashed aircraft were found in a stream draining relatively high ground to the north of Talnotry but no base-metal anomalies were found in adjacent samples.

Contamination from material derived from old mine workings is potentially more serious than other forms of contamination as it cannot necessarily be distinguished from natural occurrences of ore materials. Roads used in forestry operations have often been made from mine dump material, sometimes from a considerable distance away. Fragments of base-metal ore probably originating from the Newton Stewart area have been found within forest roads and in streams.

Contamination of streams from old mine workings is widespread in the area to the south of the Fleet granite around Pibble and in the Black Shale belt through Talnotry, but as most of the old workings are recorded dispersion trains can be traced. In some cases mine dump material can be distinguished from material dispersed naturally from mineralisation by the nature and grain size of the mineral assemblage in the concentrate samples. One sample downstream of old workings near Talnotry contains a complex association of fresh sulphides and secondary minerals and coatings, and another sample downstream of trials north of Talnotry contains relatively coarse grained fresh galena. This can be contrasted with detrital dispersion from mineralisation in upper Penkiln Burn where only secondary minerals of relatively fine grain size occur.

Comparison of sample types

Differences in the distribution patterns of the elements that have been determined in both sample types arise because of the different size spectrum of each and because of the relative upgrading of the heavy mineral fraction by panning. Particle size analysis of concentrates from the area (Leake and Smith, 1975) reveals that only a small proportion (less than 5%) of the sample is finer than 150 μm whereas the sieved sediment contains material ranging in size from 150 μm (100 BSI mesh) to less than 2 μm .

Agreement between the two sample types is best shown where an element occurs largely in minerals which are resistant to chemical breakdown, i.e. titanium in ilmenite or sphene. The distribution of elements which occur significantly in the lighter and more readily decomposed minerals, such as feldspars, is reflected only in the sieved stream sediments; lead derived from feldspars within the Fleet granite is also only detectable within the sieved sediments. Secondary precipitation of hydrous oxides of iron and manganese, which occurs particularly where streams flow through areas of impeded drainage, has a major effect on distribution patterns of these elements in the sediments, but only a minor effect on the concentrates. Distribution patterns of elements such as zinc which can be coprecipitated with or scavenged by these precipitates are also influenced in the sediments so as to display some patterns largely unrelated to the underlying rock geochemistry. There are great differences in uranium distribution between the two sample types, since soluble secondary minerals rather than resistant heavy minerals are the main source of the element.

It is apparent from a comparison of distribution patterns in both sample types that dispersion from base-metal mineralisation in the area is predominantly detrital. Panned concentrate samples are more effective in the detection

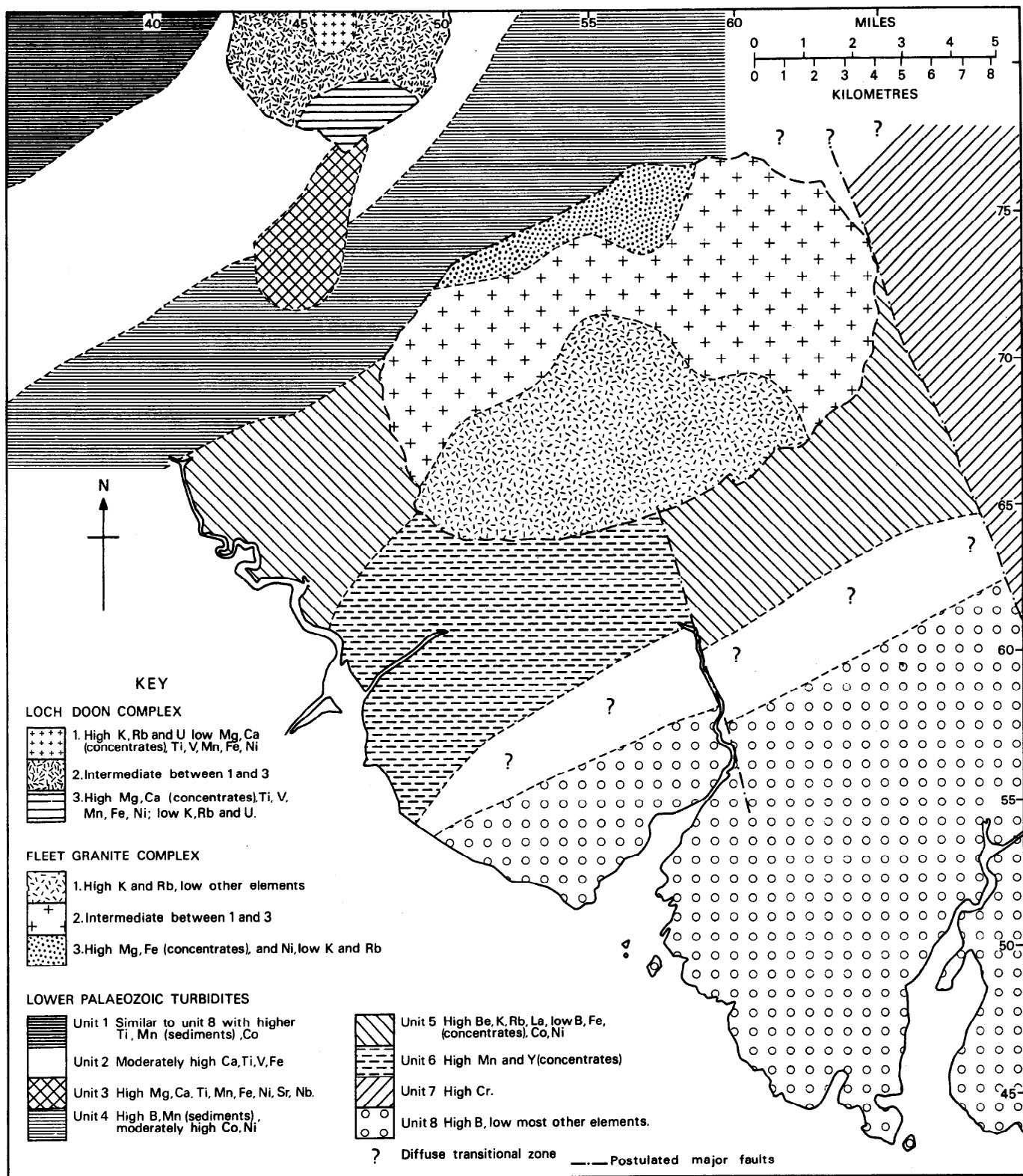


Fig. 4. Interpretation of geology based on drainage geochemistry.

TABLE 5

Comparison of levels of elements in stream sediments derived from the Criffel-Dalbeattie and the Fleet plutonic complexes

Element	Criffel complex 195 samples				Fleet complex 93 samples				t value
	\bar{x}^1 log ₁₀	\bar{x}^2	σ^1 log ₁₀	Max ppm	\bar{x}^1 log ₁₀	\bar{x}^2	σ^1 log ₁₀	Max ppm	
Li	1.86	72.4	0.14	182	.81	64.6	0.12	158	3.13
Be	1.01	10.2	0.16	20	1.00	10.0	0.21	40	0.41
B	1.78	60.2	0.20	355	1.55	35.5	0.28	245	7.12
MgO	0.20	1.58%	0.31	5.25%	- 0.06	0.87%	0.31	4.37%	6.67
K ₂ O	0.69	4.90%	0.17	12.88%	0.75	5.62%	0.19	20.42%	2.59 -
CaO	0.13	1.35%	0.26	5.01%	- 0.08	0.83%	0.17	1.95%	8.20
TiO ₂	0.15	0.71%	0.15	1.45%	- 0.24	0.58%	0.13	1.35%	5.23
V	1.86	77.4	0.18	240	1.52	33.1	0.46	174	6.88
Cr	2.06	114.8	0.23	417	1.96	91.2	0.26	263	3.17
Mn	3.33	0.21%	0.43	1.48%	3.66	0.46%	0.47	1.69%	5.73 -
Fe ₂ O ₃	0.66	4.57%	0.22	21.9 %	0.64	4.37%	0.30	29.5 %	0.57
Co	1.08	12.0	0.34	263	1.26	18.2	0.49	295	3.20 -
Ni	1.47	29.5	0.25	87	1.27	18.6	0.45	245	4.00
Cu	1.22	16.6	0.24	129	1.11	12.9	0.27	74	3.34
Zn	1.96	91.2	0.33	1445	1.91	81.3	0.47	5370	0.92
Ga	1.28	19.1	0.10	48	1.31	20.4	0.12	43	2.10 -
Rb	2.09	123.0	0.20	398	2.23	169.8	0.27	562	4.46 -
Sr	2.54	346.7	0.26	1288	2.28	190.5	0.12	347	11.66
Y	1.24	17.4	0.12	39	1.27	18.6	0.19	105	1.40 -
Zr	3.12	1318.0	0.39	7586	2.69	489.8	0.49	4169	7.43
Mo	0.10	1.3	0.25	18	0.33	2.1	0.46	57	5.96 -
Sn	0.50	3.2	0.54	324	0.34	2.2	0.49	132	2.19
Ba	2.91	912.8	0.23	1.38%	2.75	562.3	0.10	1349	8.25
La	1.70	50.7	0.31	759	1.62	40.7	0.34	269	1.92
Pb	1.81	64.6	0.29	1122	2.09	123.0	0.41	1659	5.92

¹Log₁₀ transformed data

²antilog of mean log₁₀ transformed data

TABLE 6

Comparison of levels of elements in stream sediments derived from the eight postulated units within the Lower Palaeozoic turbidites

Element	Unit 1		Unit 2		Unit 3		Unit 4		Unit 5		Unit 6		Unit 7		Unit 8	
	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ
B	1.94	0.11	1.75	0.25	1.73	0.08	1.85	0.18	1.67	0.18	1.80	0.15	1.80	0.09	1.88	0.09
MgO	0.34	0.11	0.53	0.17	0.72	0.11	0.49	0.16	0.30	0.18	0.30	0.13	0.24	0.11	0.19	0.12
K ₂ O	0.10	0.10	0.16	0.11	0.17	0.10	0.14	0.14	0.33	0.20	0.34	0.12	0.16	0.16	0.04	0.18
CaO	0.21	0.30	0.26	0.21	0.50	0.14	0.08	0.23	0.02	0.21	0.01	0.16	0.41	0.15	0.41	0.12
TiO ₂	0.03	0.09	0.05	0.13	0.09	0.11	0.05	0.09	0.09	0.07	0.12	0.09	0.11	0.05	0.12	0.05
V	2.03	0.09	2.12	0.11	2.03	0.12	1.98	0.13	1.30	0.15	1.91	0.14	1.89	0.08	1.87	0.09
Cr	2.19	0.13	2.28	0.14	2.37	0.14	2.25	0.16	2.21	0.13	2.08	0.10	2.52	0.20	2.28	0.14
Mn	0.37	0.30	0.53	0.34	0.43	0.37	0.04	0.54	0.50	0.35	0.53	0.47	0.67	0.36	0.95	0.22
Fe ₂ O ₃	0.83	0.15	0.81	0.11	0.80	0.10	0.85	0.17	0.63	0.13	0.65	0.15	0.63	0.09	0.60	0.10
Co	1.55	0.27	1.44	0.19	1.44	0.19	1.57	0.28	1.1	0.20	1.20	0.30	1.13	0.19	1.00	0.12
Ni	1.72	0.18	1.85	0.14	2.07	0.14	1.92	0.19	1.65	0.13	1.64	0.15	1.63	0.13	1.63	0.10
Rb	1.72	0.12	1.71	0.10	1.69	0.11	1.73	0.14	1.97	0.13	2.12	0.16	1.77	0.08	1.79	0.13
Sr	2.10	0.19	2.48	0.18	2.67	0.12	2.32	0.02	2.34	0.16	2.38	1.15	2.08	0.15	1.89	0.10
Zr	3.07	0.24	2.87	0.32	2.91	0.28	2.84	0.32	2.77	0.32	2.78	0.25	3.08	0.18	2.98	0.18
No of samples	17		94		34		129		37		30		15		59	

All \bar{x} and σ values for \log_{10} transformed data

of dispersion from base-metal mineralisation in the Fleet area, but these samples are also more influenced by products of contamination. The influence of secondary environmental factors on the distribution of Zn, Pb and U in sediments limits the scope of the sample in detecting hydrothermal mineralisation in some upland areas. The Cu and Ba mineralisation in the Glengap area was detected only in the concentrate samples.

Geological interpretation

The distribution of elements in alluvial samples provides valuable data for the interpretation of macro-geological features. Drainage samples can provide useful data representative of large volumes of rock, which is particularly useful where exposure is poor. The artificial concentration of heavy minerals in panned concentrates and the tendency of some streams to follow mineralised structures must be taken into account when interpreting the data.

Geochemical differences both within and between the Loch Doon and Fleet plutons are clearly apparent in the drainage data. There is general agreement on the divisions of the Doon pluton based on geochemistry and those based on mapping by Gardiner and Reynolds (1937), (Fig 2).

Within the Fleet granite the drainage geochemistry reflects some different divisions, based on element distribution, when compared to the whole rock analysis and mapping of Parslow (1968, 1971). Abundant evidence from the drainage geochemistry indicates that the most acid part of the complex occupies the south-central region (Fig. 4) where levels of B, Mg, Ca, Ti, V, Cr, Fe, Co, Ni, Zn, Zr and Ce are low but levels of Rb, and to some extent K, are relatively high. This contrasts with the part of the intrusion in the north and east which is apparently more basic. The drainage data is thus at variance with the results of a whole-rock geochemical survey of the pluton (Parslow, 1971) which indicate that the southern margin is relatively basic, although it is stated that there may be large errors in trend surfaces in the south-western part of the complex due to lack of samples from this region.

The zone of relative lithium enrichment around the outcrop of the Fleet granite is possibly of metasomatic origin, particularly as the area where lithium-rich stream sediments extend away from the granite margin correlates with the sub-surface cupola to the south-west postulated by Parslow and Randall (1973) from gravity data.

Levels of Be, K, Rb, Mo and U in samples from the southern part of the Fleet pluton, and to a lesser extent the northern part, are higher than in samples from the surrounding sedimentary rocks, while levels of Mg, Ca, Ti, V, Cr, Fe, Ni, Zn, and Ce are lower. It may be of significance that the outcrop of the Fleet granite, which is more acidic than other plutons in south-west Scotland, lies almost entirely within the outcrops of the geochemically mapped turbidite units 5 and 6 (Fig. 4) which themselves are relatively enriched in granitophile elements compared with other geochemical units within the area. This association could be explained if a significant proportion of the magma which crystallised as the Fleet granite originated by the melting of pre-existing turbidites, particularly as in the structural model of McKerrow et al. (1977) each turbidite unit can be considered as a sedimentary wedge with a considerable vertical extent.

In general stream sediment samples derived from the Loch Doon pluton are richer in Ca and Sr and poorer in Zn than those from the surrounding sediments. The central part of the pluton differs more markedly, with higher levels of K, Rb and U and lower levels of Mg, Ti, V, Mn, Fe, Co and Ni. Chromium enrichment is a feature of stream sediments from the marginal part of the Loch Doon pluton in the upper part of Curnelloch Burn and from a belt of Lower Palaeozoic rocks extending along strike further to the west-north-west beyond the boundary of the present area. The chromium is present principally in spinel, and its presumed occurrence within the Loch Doon tonalite is thought to reflect a major amount of contamination of the margin of the intrusion with material of sedimentary origin. Also of interest is the relationship between the outcrops of the most basic facies of the Loch Doon pluton within the present area and the geochemical unit 3 (Fig. 4). The geochemistry of samples derived from these two areas are very similar, yet no evidence has been found of similar igneous rock outcropping within unit 3 or of major glacial transfer of drift derived from the pluton into the area.

Significant geochemical differences between the Loch Doon and Fleet plutons and between each of these and the Criffel-Dalbeattie complex (Leake et al., 1978) are apparent from the drainage data. Table 5 compares the log mean levels of elements in stream sediments derived from the Fleet and Criffel-Dalbeattie plutonic complexes. The Fleet complex appears to be richer, in order of significance, in Mo, Pb, Mn, Rb, Co, K and Ga and poorer in Sr, Ba, Ca, Zr, B, V, Mg, Ti, Ni, Cu, Cr, Li and possibly Sn compared with the Criffel-Dalbeattie pluton. Samples derived from the section of the Loch Doon complex included in the survey are relatively poor in Be, K, Ga, Mo, Pb and U and richer in Ca and Sr compared with the other two plutonic complexes, which suggests that this part of the Loch Doon complex contains a greater proportion of plagioclase of more calcic composition.

Drainage geochemistry provides evidence for the existence of geochemical units within the turbidite sequence separated mostly by presumed major strike faults adjacent to belts of black shales. This confirms recent work (Dawson et al., 1977) concerning the subdivisions of the Lower Palaeozoic rocks based on greywacke mineralogy. Within the area around the Fleet granite eight units have been recognised from the geochemical data and the postulated approximate boundaries of these are illustrated (Fig. 4). Some adjacent pairs of turbidite units are distinguished by contrasting levels of almost the whole element spectrum, whereas other boundaries are established on the basis of only two elements. In the southern part of the area a zone of intermediate affinity separates two well defined units.

Table 6 compares the log mean levels of elements in stream sediment samples derived from the various postulated

units within the outcrop of Lower Palaeozoic rocks. Unit 3, which is geochemically the most distinct and is characterised by relatively high levels of Mg, Ca, Ni, Sr and Nb and of Ti, Mn, Fe and Zn in concentrates, has boundaries which are markedly discordant to the regional strike. Compared with samples from the other units the grain size of the ilmenite, which, together with orthopyroxene and apatite, makes up the bulk of the concentrates, is relatively coarse. Though these features suggest that the samples may have originated from a basic igneous rock no evidence of such a rock has been found in the area, nor of large amounts of glacial drift derived from the basic facies of the Loch Doon pluton to the north. As greywacke samples collected from the area are similar to types encountered outside the unit (J. D. Floyd, South Lowlands Unit, personal communication), no satisfactory explanation can be advanced to account for the composition and discordant boundaries of the unit. Geochemical Unit 2 is compositionally the nearest to Unit 3 but is also relatively inhomogeneous and may contain several distinct units with relatively narrow outcrop widths within an area of considerable structural complexity. As in Unit 3, both sample types show relative enrichment in Mg, Ca, Ti, Fe, Ni and Sr but magnitudes are lower and V levels are significantly higher. Amphibole is the main mafic silicate observed in concentrate samples from this unit. Geochemical Unit 4, which occurs to the south-east of Unit 2, is also relatively basic but the drainage samples are generally less rich in Mg, Ca, Ti, V and Ni and levels of B, Mn, Co and Ni in the sieved sediments are higher, though this in part at least could be due to differences in the physical environment.

The average compositions of stream sediments derived from the other 5 geochemical units are significantly less basic. Units 5 and 6 are very similar in composition, both being relatively rich in Be, K and Rb. The only significant compositional differences between the two units are higher levels of B, Cr and Rb in stream sediments and particularly of Mn and Y in concentrates derived from Unit 6. The Mn and Y are accommodated largely in spessartitic garnet which is particularly abundant in some samples. In view of the very close similarity in composition between the units it is possible that the differences in composition reflect superimposition of elements derived from hydrothermal mineralisation (which is relatively intense within Unit 6) and contact metamorphism, since a relatively wide aureole has been mapped to the south-west of the Fleet granite coinciding broadly with the region of the subsurface granite cupola as postulated by Parslow and Randall (1973). Units 7 and 8 are also relatively similar in composition, the most significant difference being the relatively high Cr content of samples derived from Unit 7. Unit 1, which outcrops in the extreme north-west of the area, can be equated with the Afton Formation, characterised by greywackes rich in quartz but poor in ferro-magnesian minerals (Dawson et al., 1977). Compared with Units 5 to 8, sieved sediments derived from this formation are relatively rich in B, Ti, V, Mn, Fe, Co and Ni.

METALLIFEROUS MINERALISATION

The geochemical drainage survey of the Fleet area provides evidence of six main types of hydrothermal mineralisation together with some other isolated occurrences.

Mineralisation within belts of black shale and associated rocks

A prominent series of lead, copper and zinc anomalies occurs in the upper part of the Penkiln Burn drainage basin, in streams mostly draining outcrops of hornfelsed black shale and associated cherts and volcanic rocks. One drainage anomaly containing high levels of lead in both concentrate and sieved sediment samples, from a stream in the headwaters of the basin draining the region of Lamachan Hill where the outcrop of the Black Shale belt is relatively wide, has been followed up in detail (Leake et al., in preparation). Surface expression of mineralisation was found in the form of gossan in a north-south fault zone and contained a complex intergrowth of goethite, limonite, plumbogummite, beudantite and a little malachite. Soil sampling and shallow drilling revealed a much wider distribution of mineralisation, with veinlets and disseminations containing either sphalerite, galena, chalcopyrite and bornite or secondary lead phosphate minerals. The incidence of sphalerite mineralisation appeared much greater than indicated either from the drainage samples or surface material, possibly as a result of preferential leaching of zinc in surface material relative to lead. The mineralisation distribution appears to be controlled both by counter Caledonoid structures, and by the distribution of layers of rocks other than black shales within a structurally complex area containing many strike faults.

Within the belt of black shales along the north-western and northern contacts of the Fleet granite there are several base-metal drainage anomalies, though, unlike the Lamachan area, zinc is more conspicuous than lead. Follow-up of drainage anomalies and the elucidation of mineralisation controls within this area of complex geology are particularly difficult in view of the dense forest cover of much of the belt. Several thin strike-trending mineralised structures occur containing varying proportions of galena, sphalerite, malachite and chalcopyrite and there are old workings in some of these. North of the black shale belt there is small-scale quartz-carbonate vein mineralisation containing chalcopyrite and sphalerite in the lower part of Darnaw Burn near Clatteringshaws Loch. East of Clatteringshaws Loch the drainage samples provide less evidence of base metal mineralisation although mimetite (Dawson et al., 1977) is abundant in one stream draining old workings at Craigshinnie.

Vein mineralisation marginal to the Fleet granite

South and south-west of the Fleet granite there are several base-metal anomalies derived from lode structures which

have been widely worked in the past (Wilson, 1921). Some drainage samples provide evidence of extensions of mapped mineralised structures, such as a westward extension of the structure worked at Pibble mine, and possibly of unrecognised mineralisation to the west of Culcronchie but in view of the possible contamination from the widespread mining activity this is uncertain. A general correlation exists between this area of mineralisation, the zone of relative lithium enrichment and the postulated region of the subsurface cupola of the Fleet granite (Parslow and Randall, 1973). There is also evidence from the relative distribution of lead, zinc and copper anomalies of a zonation in mineralisation, with copper predominant adjacent to the present outcrop of the Fleet granite.

Mineralisation within the Fleet granite

Previous investigations (Tandy, 1974) lead to the discovery of minor molybdenite mineralisation associated with quartz-muscovite veins in the marginal part of the Fleet granite to the east of Talnotry and in quartz and aplite veins within the southern contact zone between Culcronchie Burn and the Water of Fleet. The distribution of drainage molybdenum anomalies within the intrusion suggests that similar mineralisation may be of more widespread occurrence within the pluton but no follow-up of these has been carried out within the present survey.

Mineralisation associated with a major lineament

Drainage anomalies indicate the presence of base-metal mineralisation within a prominent lineament following the regional strike of the sedimentary rocks from north of Gatehouse of Fleet through the vicinity of Glengap to east of Loch Mannoeh. Several thin carbonate veins containing small amounts of galena and chalcopryrite have been found in the Glengap area and boulders containing vein baryte and some malachite were observed in the stream which follows the lineament to the east of Loch Mannoeh.

Copper vein mineralisation

Between Gatehouse of Fleet and Kirkcudbright drainage samples provide evidence of chalcopryrite-bearing mineralisation in an eastward extension of the structure worked at Enrick mine and possibly of other similar structures. As copper is predominant and the structure trends in a similar direction to several structures around the porphyry-style copper mineralisation at Black Stockarton Moor (Brown et al., in preparation) it is possibly related to this centre of subvolcanic igneous activity.

CONCLUSIONS

A study of the distribution pattern of a suite of elements in drainage samples identified areas of potential metalliferous mineralisation where detailed follow-up work was undertaken. The maps presented show a number of patterns directly related to the composition of the Lower Palaeozoic sediments and the major igneous plutons. The main conclusions drawn from the survey are as follows:

1. Detailed follow-up investigations of drainage anomalies in the upper part of the Penkiln Burn drainage basin led to the discovery of both structure-controlled and disseminated mineralisation. Minerals found included sphalerite, galena, chalcopryrite and bornite in addition to secondary lead phosphate minerals. The mineralisation occurs in hornfelsed black shales, cherts and rocks of volcanic origin (Leake et al., in preparation). Several drainage anomalies found within a similar belt of black shale to the north-west of the Fleet granite are indicative of small occurrences of base metal mineralisation.
2. The distribution of Cu, Pb and Zn in drainage samples suggests zonation of vein mineralisation to the south and south-west of the Fleet granite. Copper is prominent adjacent to the margin of the granite with zinc and particularly lead showing a wider distribution away from the granite. This area of vein mineralisation is also characterised by a roughly coincident zone of lithium enrichment in stream sediments and by panned concentrates containing spessartite garnet probably derived from contact metamorphism. This zone is also broadly coincident with the sub-surface cupola of the Fleet granite postulated from gravity data by Parslow and Randall (1973).
3. Minor molybdenite mineralisation is known to occur within the south and west margins of the Fleet granite. A study of the distribution of molybdenum in drainage samples suggests that this type of mineralisation may occur over a wider area within the pluton.
4. Follow-up investigations of drainage anomalies have also led to the discovery of a prominent mineralised lineament which follows the regional strike of the Lower Palaeozoic sediments from north of Gatehouse of Fleet eastwards beyond Loch Mannoeh. Within this structure vein mineralisation containing small amounts of galena and chalcopryrite have been found. Boulders derived from this structure contain vein baryte and malachite.
5. The distribution of copper in drainage samples east of Gatehouse of Fleet suggests a wider distribution of copper-bearing vein mineralisation similar to that worked at Enrick mine.

6. The Lower Palaeozoic sediments have been divided on the basis of drainage geochemistry into eight units. The unit in the north of the area correlates with the Afton Formation characterised by greywackes rich in quartz but poor in ferromagnesian minerals (Dawson et al. , 1977).
7. Drainage geochemistry provides evidence of subdivisions within the Fleet granite, the boundaries of which differ to some extent from those shown by Parslow (1968, 1971) on the basis of geological mapping and a limited number of whole rock analysis. Within the Loch Doon pluton there is good agreement between drainage geochemistry and the units mapped by Gardiner and Reynolds (1932).

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APPENDIX I: GEOCHEMICAL MAPS AND DESCRIPTION OF ELEMENT DISTRIBUTION

Class intervals plotted for all elements with the exception of U (concentrates) and Sb (concentrates) have been based on the changes in slope of the cumulative frequency diagrams. Class intervals for U and Sb in panned concentrates have been based on an estimate of the analytical detection limit together with arbitrary limits.

Lithium (sediment)

Stream sediment samples with the highest lithium contents are confined with one exception to the contact zone of the Fleet granite. In the south-western part of the contact zone relatively lithium rich sediments occur up to 3 km from the margin of the intrusion. In view of the subsurface cupola postulated by Parslow and Randall (1973) on the basis of gravity data to extend south-westwards from the Fleet granite outcrop it is considered that the relative lithium enrichment in this area and in other parts of the contact zone may originate from a metasomatic or hydrothermal introduction of the element into the country rocks adjacent to or above the crystallising granite. Bowler (1959) found great enrichment of lithium in sediments surrounding the granites of south-west England far in excess of sediments which had not undergone thermal metamorphism.

Beryllium (sediment)

Higher levels of beryllium are present in stream sediments derived from the Fleet granite than those derived from the Criffel plutonic complex (Leake et al., 1978). Within the outcrop of the Fleet granite beryllium distribution is not highly correlated with that of elements which express large scale compositional variation within the pluton and therefore it may be influenced by hydrothermal activity.

Boron (sediment)

The stream sediments derived from both the Fleet and the Loch Doon plutons are relatively depleted in boron compared with their surroundings. Within the outcrop of Lower Palaeozoic rocks there are also zones with stream sediments relatively low in boron (units 2 and 5 in Fig. 4). Some samples with relatively high boron concentrations, such as from the upper part of Culcronchie Burn, and others further to the south-east contain boron of hydrothermal origin associated with base metal mineralisation. Tourmaline has been identified in concentrates from some of these sites. The most obvious grouping of samples with relatively high boron concentrations occurs to the north-east of Clatteringshaws Loch in an area also generally enriched in vanadium, manganese, iron and cobalt, probably due to secondary environmental factors.

Magnesium oxide (sediment)

The vast majority of samples within the lowest concentration class are derived from the Fleet granite, those with the minimum values (0.2 - 0.4% MgO) occurring to the south and south-east of Loch Grannoch. This area coincides to some extent with the outcrop of the fine-grained biotite-muscovite granite (Parslow, 1971) but extends further south. Comparison of the drainage map and a plot of a cubic surface of magnesium oxide in rocks from the Fleet pluton (Parslow, op. cit.) shows major differences. Though there is agreement in that an area of relatively high magnesium occurs in the extreme north of the intrusion, to the east and south-east of Clatteringshaws Loch, there is disagreement elsewhere, particularly in the west where the cubic surface indicates a region of low magnesium abundance (less than 0.5% MgO), and in the south where it indicates a region of high magnesium abundance (greater than 1.5% MgO). It is considered possible that the stream sediment samples provide a better expression of the large-scale geochemical variation within the Fleet pluton than the relatively small number of rock samples analysed by Parslow (op. cit.). Major modification of the geochemical patterns by transported glacial drift is considered unlikely in view of the sharp geochemical boundary of the Fleet granite, particularly in the south for Mg and many other elements.

Within the Lower Palaeozoic rock outcrop samples in the highest concentration class (maximum 8.5%) are derived particularly from the black shale belt adjacent to the north-western margin of the Fleet pluton near Talnorty (geochemical unit 3). Orthopyroxene is a prominent constituent of samples from this area and accounts for the relative magnesium enrichment.

Compared with the Fleet pluton, the Loch Doon plutonic complex appears more magnesium-rich, especially the southern part around Loch Dee which can be correlated with the relatively basic facies or norite (Gardiner and Reynolds, 1937). In the Loch Doon complex the lowest magnesium levels occur in samples derived from the area to the east of Loch Valley where the central core of adamellite (Gardiner and Reynolds, op. cit.) outcrops. The magnesium content of these samples is significantly greater than those derived from the central porphyritic facies of the Main Criffel granodiorite (Leake et al., 1978).

Potassium oxide (sediment)

Samples with the highest potassium concentrations (3.5% - 10% K₂O) are mostly derived from the Fleet granitoid complex but the distribution is more complex than other elements. Parslow (1971) also found the distribution of potassium and modal microcline in rock samples from the Fleet granite to be complex.

Within the outcrop of the Lower Palaeozoic turbidites stream sediment samples with relatively high potassium are

associated with geochemical units 5 and 6 (Fig. 4) and terminate to the northwest against the black shale belt that runs through Talnотry.

Calcium oxide (sediment)

There is considerable contrast in calcium concentrations of stream sediments derived from different parts of the outcrop of Lower Palaeozoic rocks, which can be related to the distribution of greywacke types of contrasting mineralogical composition.

Stream sediments indicate that the Loch Doon plutonic complex is more calcic overall than the Fleet granite but comparable to the most basic parts of the Main Criffel granodiorite (Leake et al., 1978). The calcium content of samples derived from the Fleet granite is fairly comparable with those derived from the central porphyritic facies of the Main Criffel granodiorite (Leake et al., *op. cit.*). Within the Fleet granite, samples with the lowest calcium concentrations occur in the area to the south and south-east of Loch Grannoch. This distribution shows a slight correlation with the cubic surfaces of modal oligoclase and calcium oxide in rock samples (Parslow, 1971) except in the southern part of the intrusion.

Calcium (concentrate)

The distribution of calcium in concentrates is generally similar to that in the stream sediment samples except for an area between Gatehouse of Fleet and Kirkcudbright where only the concentrate samples are relatively calcium-rich. As this area is also relatively enriched in detrital iron and copper minerals in the drainage samples it is possible that the calcium is accommodated in relatively coarse carbonates derived from vein structures, a few of which have been worked on a small scale in the past. The zone of calcium enrichment within geochemical unit 3 (Fig. 4) is also strongly apparent in the concentrates and clinopyroxene, which occurs in close association with orthopyroxene, has been identified as the main mineral host. Pyroxene, hornblende and sphene are the main hosts in the calcium-rich samples derived from the southern part of the Loch Doon plutonic complex. A narrow calcium-rich zone which probably corresponds to a distinct greywacke formation is apparent from the concentrates to the south-east of Loch Trool.

Titanium oxide (sediment)

Samples with the lowest titanium contents are most derived either from the southern part of the Fleet granite or the central part of the Loch Doon complex. Within the outcrop of Lower Palaeozoic sediments the titanium levels in samples north-west of the black shale belt through Talnотry are higher than those originating from rocks to the south-east of this line. There is also a grouping of particularly titanium-rich samples in the upper reaches of Pulnee Burn and adjacent streams which corresponds approximately with the boundaries of geochemical unit 3 (Fig. 4).

Titanium (concentrate)

Titanium distribution is better defined in concentrate samples, particularly within the outcrop of the Lower Palaeozoic rocks. Samples with the highest titanium values are derived from geochemical unit 3 (Fig. 4). Abundant ilmenite, coarser than found elsewhere in the sediments, accounts for the titanium enrichment. A further less intense zone of titanium enrichment is shown by samples derived from the north-west part of geochemical unit 2 (Fig. 4) but unlike the previous example the zone appears to follow the regional strike. Abundant coarse grained anatase has been detected in samples from this area (Dawson et al., 1977).

Distribution patterns within the pluton are similar to those shown by stream sediments, the highest titanium concentrations being derived from the most basic facies of the Loch Doon pluton around Loch Dee.

Vanadium (sediment)

Samples with the lowest vanadium concentrations are largely confined to the central part of the Loch Doon pluton and to the southern and central parts of the Fleet pluton. The correlation coefficients (Table 3) between vanadium and other elements are dominated by this contrast in composition between these parts of the intrusive complexes and the surrounding Lower Palaeozoic rocks. Vanadium levels are relatively high in samples derived from the geochemical units 2 and 3 (Fig. 4). Scattered vanadium-rich samples from elsewhere in the area have no clear associations with other elements.

Chromium (sediment)

Stream sediments containing relatively low levels of chromium are confined to the outcrop of the Fleet granite, and to the central part of the Loch Doon pluton. There is a marked concentration of chromium-rich samples to the east of the presumed counter Caledonoid fault through Woodhall Loch. Chromium enrichment is also a feature of stream sediments derived from the marginal tonalitic facies of the Loch Doon pluton in the upper part of Curnelloch Burn. North of the boundary of the area a zone of chromium-rich stream sediments can be traced along strike into the margin of the Loch Doon pluton, a situation analogous to the distribution of chromium in stream sediments on the north side of the Main Criffel granodiorite (Leake et al., 1978). This apparent existence of a chromium-rich horizon in the edge of the Loch Doon pluton may be a reflection of a major amount of contamination of the margin of the intrusion with xenoliths and resorbed material of sedimentary origin.

Manganese (sediment)

The concentration range for manganese (from 200 ppm to 23.7%) is greater than for other elements in stream sediments and there is frequently considerable manganese enhancement by precipitation of hydrous oxides where streams flow through boggy environments. Nevertheless some correlation between stream sediment manganese levels and variation within the underlying geology can be demonstrated. Samples within the lowest manganese concentration class are mostly derived from the Lower Palaeozoic turbidites in the south and south-east of the area where the relief is relatively subdued and also from the central part of the Loch Doon pluton. In contrast there is a concentration of samples from the highest class within geochemical units 3 and 5 (Fig. 4).

Within the Fleet granite manganese-rich samples are confined to the northern and eastern parts of the outcrop with lower levels in the central and southern parts. Some of the manganese present in samples from the Glengap and Pibble areas may be of hydrothermal origin as several mineralized structures occur within these areas.

Manganese (concentrate)

There are major differences in manganese distribution patterns shown by the two sample types. A prominent group of concentrates very rich in manganese occurs to the west of Pibble, and garnet has been identified in these samples as the main host. Very manganese-rich samples also occur in samples derived from geochemical unit 3 (Fig. 4) and in these orthopyroxene and ilmenite have been identified as the main manganese host minerals. It is apparent that, within the outcrop of the Fleet granite, precipitated manganese oxide forms a major proportion of the sieved sediment samples in view of the lack of corresponding manganese-rich concentrates. Within the outcrop of the Loch Doon pluton there is a much closer agreement between sediments and concentrates, a central area of relative manganese depletion being apparent in both.

Iron oxide (sediment)

Samples with the lowest iron concentrations are largely confined to the outcrops of the plutonic complexes and in particular to the central part of the Loch Doon granite. There are several stream sediments derived from the Fleet granite containing high levels of iron, probably originating by secondary precipitation in streams draining boggy areas. Though distribution patterns are diffuse it is evident that there are a much greater number of relatively iron-rich samples derived from the Lower Palaeozoic rocks within and north-west of the black shale belt that passes through Talnotry.

Iron (concentrate)

Over the Fleet granite samples containing very low levels of iron predominate which differs from iron distribution in the stream sediments. Within the Loch Doon pluton the iron content of concentrates is clearly related to the outcrops of the different members of the complex and to hematite mineralisation to the west of Loch Dee. The group of iron-rich samples to the south-south-west of Loch Dee correspond to the area of Ca, Ti and Mn enrichment.

There is a tendency for the concentrates derived from geochemical unit 2 (Fig 4) to be richer in iron than those originating from other parts of the Lower Palaeozoic outcrop. Another group of samples with high iron concentrations are associated with the black shale belt in the vicinity of Talnotry. Pyrite and almandine in addition to oxide minerals have been identified as the main iron bearing hosts. Other anomalous samples occur to the north and north-east of Clatteringshaws Loch which contain conspicuous pyrite and some fragments of steel wire (Fortey, 1975). The iron in the samples from each of Loch Mannoich are derived from vein mineralisation which follows a prominent lineament trending south-west through Glengap and several iron-rich samples from the east of Gatehouse of Fleet are also derived from mineralisation.

Cobalt (sediment)

Distribution patterns of cobalt in stream sediments are complex and only partially related to the underlying rock geochemistry as a result of the high degree of association with environmentally controlled secondary accumulations of manganese oxides. The relative enrichment of cobalt in samples derived from geochemical units 1 to 4 (Fig. 4) compared with those to the south probably reflects a major compositional difference in the greywacke sediments. South of the Fleet granite there are several moderately cobalt-rich samples both in the Pibble and Glengap areas, some of which are only moderately enriched in manganese, so that for these a cobalt contribution from hydrothermal mineralisation can be deduced.

Within the Fleet granite there is a wide range of cobalt concentrations but relatively cobalt-rich samples in the northern part of the outcrop show a strong correlation with manganese. Within the Loch Doon pluton the central adamellite facies can be distinguished from the marginal tonalite and diorite by the relatively low cobalt values. There is a prominent group of cobalt-rich samples to the north and north-east of Clatteringshaws Loch, but as manganese levels in the area are also relatively high, this probably represents a wide area of secondary enrichment.

Nickel (sediment)

Relatively high levels of nickel are prevalent in samples derived from geochemical units 3 and 4 (Fig. 4), the dioritic

facies of the Loch Doon pluton and an area to the south of the Fleet granite. The nickel content of samples obtained from the stream draining the edge of the niccolite-bearing massive sulphide occurrence at Talnotry is relatively low compared with other nearby samples.

Nickel (concentrate)

The distribution patterns differ from those shown by the sediments due to enhancement in the concentrate samples. Samples with the highest nickel contents are confined to geochemical unit 3 (Fig. 4), where orthopyroxene has been identified as the main host, and to the dioritic facies of the Loch Doon pluton.

Unlike the sediments, nickel enrichment in the sedimentary rocks south of the Fleet granite is not apparent in the concentrates.

Copper (sediment)

Copper anomalies in stream sediments are grouped within the area of black shale outcrops in the vicinity of Lamachan and within, or to the north of, the belt of black shale adjacent to the Fleet granite around Talnotry. Base metal mineralisation, in the area drained by the headwaters of Penkiln Burn (Leake et al., in preparation), has gossan surface expression containing minor amounts of malachite. Further downstream copper anomalies are probably derived from similar mineralisation as the assemblage of minerals in the concentrate samples is similar to that found in the headwaters.

Within the Talnotry black shale belt the largest anomaly is derived from a small strike trending mineralised structure containing malachite [grid ref. NX 4955.7264]. Elsewhere within this belt rich disseminations of pyrite containing small amounts of chalcopryrite (i. e. near Murray's Monument, grid ref. NX 4876.7185) are widespread. North of the black shale belt two small anomalies in the headwaters of streams are probably the result of secondary environmental enrichment as precipitation of iron and manganese occurs at these sites.

In the Clatteringshaws Loch area anomalies are derived from chalcopryrite bearing quartz-calcite vein mineralisation which has been worked at a small trial [grid ref. NX 5308.7679]. Further upstream concentrate samples provide evidence of further mineralisation (Dawson et al., 1977). A minor amount of chalcopryrite has been found in a concentrate sample upstream of the anomaly on the eastern side of Clatteringshaws Loch. South and west of the Fleet granite there are several sites with anomalous levels of copper which are probably derived from the base metal vein mineralisation which is widespread in the area between Newton Stewart and Fibble. The highest anomalies are derived from a chalcopryrite-bearing structure which trends roughly east-west in the upper part of Culchronchie Burn.

Within the Fleet granite copper levels of stream sediments are generally lower than in the surrounding rocks. The anomalous site at the edge of the pluton near Loch Ken is probably derived hydromorphically from a dispersed source within the sulphide-rich hornfelsed black shales which outcrop nearby. At other anomalous sites within the Fleet granite, such as in the lower reaches of Lowring Burn, environmental enrichment of copper is suspected as this is an area of conspicuous secondary manganese and iron precipitation. The only anomalous site within the Loch Doon pluton which also has a corresponding large concentrate anomaly is derived from a local source within the dioritic facies of the Loch Doon complex.

Copper (concentrate)

Except in the south-eastern part of the area there is broad agreement in the general location of copper anomalies in concentrates and sieved sediments. Chalcopryrite and malachite have been identified in many of the anomalous concentrates. Concentrate copper anomalies without corresponding sieved sediment anomalies occur in the headwaters of Caldons Burn and at two sites, east [NX 468.613] and north-east [NX 444.671] of Newton Stewart. In the former area anomalous concentrations of zinc and lead also occur but the source of these has not been found. In the latter two cases the relatively high levels of tin indicate contamination of the sites with metallic rubbish but secondary zinc and lead minerals and galena and sphalerite respectively have also been identified.

In the south-east of the area several concentrate anomalies are derived from the mineralised east-north-east trending lineament in the Glengap area and to the east of Loch Mannocho and chalcopryrite has been identified in some of the samples.

Between Gatehouse of Fleet and Kirkcudbright there are several concentrate anomalies, some of which are derived from the copper-bearing vein mineralisation that was worked in part at the Enrick Mine. As geochemically similar samples occur further to the east it is possible that this structure extends in this direction and that other similar mineralisation occurs elsewhere in the area. Two anomalies from south-east of Loch Mannocho may be derived from contamination as visible evidence of metallic rubbish is widespread at these sites.

Zinc (sediment)

Within the Fleet granite the two high zinc anomalies are from sites with enrichment in secondary manganese. South of the Fleet granite there are isolated zinc anomalies, some of which can be related to the presence of vein mineralisation, e. g. Upper Culchronchie Burn (NX 5084.6373), near Fibble (NX 5158.6055) where contamination from mine dump material is suspected and west of Glengap (NX 6312.5884) where sphalerite has been identified and minor carbonate veins have been observed upstream.

The largest concentration of zinc anomalies occurs within the belt of black shales adjacent to the Fleet granite

between Talnotry and Craigshinnie where several occurrences of sphalerite mineralisation are known or suspected. Environmental enrichment of zinc from a dispersed source is considered to account for several anomalies to the north of this belt and to the north-west of Clatteringshaws Loch. A few zinc anomalies are associated with the black shale belt through Lamachan where evidence of base metal mineralisation is widespread.

Zinc (concentrate)

Compared with samples from the surrounding rocks, concentrates derived from the Fleet granite and more central parts of the Loch Doon pluton are relatively zinc deficient. The majority of concentrates with anomalous levels of zinc that have been examined mineralogically contain a significant amount of sphalerite. In a few cases a relatively high content of spinel, which occurs in addition to orthopyroxene and ilmenite in samples from the upper part of Pulnee Burn and in some samples from north-east of Clatteringshaws Loch, accounts at least in part for zinc anomalies, since semiquantitative XRF scanning has shown the mineral to contain a significant amount of zinc. Small amounts of sphalerite have also been observed in a few concentrates with a zinc content less than 150 ppm, particularly within the Penkiln Burn drainage basin.

Apart from vein mineralisation to the east and north of Newton Stewart and the mineralised lineament near Glengap, evidence of zinc mineralisation from concentrates is most abundant within the black shale belts through Talnotry and Lamachan, segments of the latter outcropping further south in Penkiln Burn. With allowance for secondary environmental enrichment of zinc in stream sediments at some sites, agreement between anomalies in the two sample types is moderately good. One exception is provided by the upper part of Caldons Burn where zinc anomalies occur only in the concentrates.

Gallium (sediment)

Distribution patterns for gallium in sieved sediments are relatively diffuse as a result of the low regional variance (Table 1). Relatively gallium-rich samples are concentrated within and immediately around the Fleet granite and scattered over the Lower Palaeozoic rocks which form units 2-4 (Fig. 4). The moderately strong positive correlation between gallium and lead, manganese, cobalt and iron (Table 3) is possibly an expression, particularly within the Fleet granite, of a common source with lead in the weathering products of feldspar and accumulation of this material at sites where active precipitation of secondary iron and manganese oxides is pronounced. There is also a significant correlation between gallium-rich and manganese-rich sites outside the outcrop of the Fleet granite.

Rubidium (sediment)

Stream sediment samples with the highest rubidium contents are confined to the outcrop of the Fleet granite, particularly to its central and southern parts, whereas the central facies of the Loch Doon pluton is the only part of this complex showing relatively high levels. The black shale belt through Talnotry marks a boundary between turbidites providing moderate levels of rubidium in stream sediments to the south-east and relatively rubidium-poor rocks to the north-west. This distribution is very similar to that shown by potassium and is interpreted as indicating the presence of greywackes containing significant detritus of granitic composition.

Strontium (sediment)

The strontium content of samples derived from the Fleet granite are much lower than those derived from the Loch Doon complex. Within the Loch Doon pluton the highest levels of strontium occur over the dioritic facies to the south. The very high positive correlation between strontium and calcium (Table 3) indicates that much of the strontium originates from plagioclase.

A group of relatively strontium-rich samples coincide approximately with geochemical unit 3 (Fig. 4), in which some of the strontium may be accommodated in apatite as significant amounts have been identified in concentrate samples. Baryte also contributes to the strontium content of some samples from the area.

Yttrium (concentrate)

Yttrium contents of stream sediments are not presented in map form because of the low ratio between regional and total sampling variance (Table 1).

Yttrium distribution patterns are diffuse. Samples with the lowest yttrium contents are concentrated over the southern and central parts of the Fleet granite. Samples derived from the Fleet granite with higher yttrium contents correlate to some extent with those with high titanium levels, and sphene has been identified as a host mineral in some of these samples. The most notable concentration of relatively yttrium-rich samples occurs to the south-west of the Fleet granite where garnet has been identified as the main yttrium-bearing mineral. This association is responsible for the relatively high degree of correlation between yttrium and manganese (Table 4). In one sample from the same area [NX 4899.6378] a significant amount of monazite has also been identified.

Zirconium (sediment)

Zirconium distribution patterns in stream sediments are relatively diffuse because of low sampling and analytical precision. Nevertheless it is apparent that the southern and central parts of the Fleet granite are relatively zirconium poor whereas the Loch Doon complex is appreciably richer in zirconium. Within the outcrop of the Lower

Palaeozoic rocks to the south of the Fleet granite there appears to be a break, marked by the Water of Fleet, between relatively zirconium-poor samples to the west and more zirconium-rich samples to the east. This may represent a counter-Caledonoid fault separating greywacke units of contrasting composition.

Zirconium (concentrate)

As the sampling precision for zirconium in concentrate is relatively poor, distribution patterns are diffuse and there is considerable difference in detail between the two sample types. The zirconium contents of samples derived from the Fleet granite are low, particularly in the southern part. Within the outcrop of Lower Palaeozoic rocks there are discrete groups of relatively zirconium-rich samples, e.g. to the south-west of Woodhall Loch and to the east of Gatehouse of Fleet which often do not correspond with zirconium-rich sieved sediment samples.

Niobium (concentrate)

The distribution patterns for niobium are diffuse but overall there is a highly significant positive correlation with titanium. The most obvious group of niobium-rich samples correspond to geochemical unit 3 (Fig. 4) in which ilmenite has been identified as the main host mineral. There are three other groups of niobium-rich samples to the south of the Fleet granite, two of which correspond moderately well to zones of titanium enrichment within the greywackes. To the east of Greetown niobium is associated with a zone of manganese enrichment.

Molybdenum (sediment)

With one exception, most samples with the highest molybdenum values are derived from the Fleet granite but distribution is irregular. Previous investigations (Tandy, 1974) led to the discovery of a number of quartz-muscovite veins with minor molybdenite in the marginal parts of the granite east of Talnorty. Molybdenite also occurs in small quartz and aplite veins along the southern margin of the intrusion between the Water of Fleet and Culcraonchie Burn. Molybdenum shows its greatest positive correlation with uranium at several sites within the Fleet granite, i.e. the lower part of Lowring Burn. As several of these samples also contain major amounts of secondary iron and manganese oxides some secondary environmental enrichment is predicted such as occurs in the Shin area of Northern Scotland (Leake and Smith, 1975). The lack of significant positive correlation between molybdenum and manganese in the data indicates that, in most cases, the molybdenum anomalies are ultimately derived from discrete sources of minor molybdenite mineralisation.

Tin (concentrate)

The tin content of samples within the upper two concentration classes is in most cases derived from metallic contamination either from old mineral workings, as at Craigshinnie, or from human habitation or farming activities which are most widespread in the south-eastern part of the area. The exact form of the tin is not known but the abundance of tin cans at some sites and the significant positive correlation between tin and lead (Table 4) indicate that solder is an important source. The tin anomalies within the outcrop of the Loch Doon pluton are from sites remote from human habitation but forestry road building in the area could give rise to contamination. The sample with a small detectable tin content to the south-west of Lamachan is the most remote from human activity and is therefore the most likely to be of natural origin though the existence of several crashed aircraft in the upland areas is another possible source of contamination. In view of the identification of a grain of toad's-eye tin in a concentrate from a site west of Clatteringshaws Loch /NX 5025.7617/ (Dawson et al., 1977) it is possible that this mineral may account for some weak anomalies over the turbidites within the upland areas.

Antimony (concentrate)

Only six concentrate samples contain detectable levels of antimony. The highest concentration (25 ppm) occurs in a sample derived from Craigshinnie Burn which drains old workings and is rich in mimetite (Dawson et al., 1977). The sample from the headwaters of Penkiln Burn near Lamachan is rich in plumbogummite and base metal mineralisation which occurs upstream of the site contains minor amounts of antimony (Leake et al., in preparation). No explanation can be provided for the four other concentrates as other elements associated with base metal mineralisation are not enriched in these samples.

Barium (sediment)

There are few relatively barium-rich samples and except for a few associated with the southern part of the Loch Doon pluton these are scattered through the area. At several sites there is a correlation between barium and very high levels of secondary manganese oxides. There are a few exceptions to this association, e.g. the sample to the south-east of Clatteringshaws Loch, where baryte is the probably source in view of its identification in a concentrate sample from the next stream to the east. Baryte mineralisation also accounts for the barium anomalies in the upper part of Culcraonchie Burn and probably contributes to the sample from north of Clatteringshaws Loch. The source of the barium anomaly from the tributary of Penkiln Burn to the west of Talnorty is unknown.

Barium (concentrate)

The very low number of barium-rich concentrate samples demonstrates the rarity of baryte as a component of base metal mineralisation within the area. There is only one site, in the aureole of the Loch Doon pluton to the south of Loch Dee, where high barium occurs in both sample types. Major amounts of baryte occur only in samples derived from the mineralised lineament to the east of Loch Mannoch and in a sample downstream of copper-bearing vein mineralisation to the east of Gatehouse of Fleet. Baryte has also been visible in several other concentrates in sample from the headwaters of Penkiln Burn, in the Glengap area, Culcraichie Burn, north of Clatteringshaws Loch and west of Lowring Burn within the outcrop of the Fleet granite.

Cerium (concentrate)

Relatively cerium-rich samples occur in the stream to the west of Culcraichie Burn where monazite is fairly abundant. Streams draining the eastern part of the Fleet granite, where sphene has been identified as the host mineral, are also cerium-rich. Cerium does not show the same degree of enrichment as yttrium in the garnet-rich concentrate from the area to the south-west of the Fleet granite.

Lead (sediment)

Distribution patterns of lead in sediments are complex as anomalies are derived from several sources. Lead anomalies derived from base metal mineralisation, associated with the black shale belt, occur in the upper part of the Penkiln Burn drainage basin (Leake et al., in preparation) and at sites adjacent to the north-west contact of the Fleet granite, i. e. Grey Mare's Tail (NGR. NX 4912.7257) (Dawson et al., 1977). Anomalies derived from lode structures occur at sites south of the Fleet granite in the vicinity of Pibble and west of Loch Mannoch, where the stream follows a mineralised lineament containing baryte and minor sulphides.

In some cases it has been shown that anomalies are not directly associated with base metal mineralisation. Within the Fleet granite several anomalies (up to 2120 ppm Pb) are due to lead which has been derived from residual weathering products of potassium feldspar, an association that is reflected in the relatively high correlation between lead and gallium (Table 3). At several of these sites and others secondary enrichment of lead is suspected because of the coincidence with particularly high levels of secondary manganese and iron oxide.

Metallic contamination appears to have less influence on the sediments than on the concentrates although some anomalies in the farming area between Gatehouse of Fleet and Kirkcudbright may be due to such material.

Lead (concentrate)

There are major differences in the distribution patterns of lead in concentrates compared to sieved sediments, with a marked lack of lead-rich concentrates within the outcrop of the Fleet granite. Concentrate lead anomalies indicative of base-metal mineralisation occur along the east-north-east trending mineralised lineament near Glengap where thin veinlets with galena have been found, at several sites within the Pibble area and to the north and east of Newton Stewart where several vein structures containing galena have been worked in the past. Further lead anomalies occur around Talnotry and further to the north-east, and galena has been identified in several structures parallel to the regional strike. At Craishinnie a sample downstream of old workings contains abundant mimetite (Dawson et al., 1977). The most conspicuous grouping of lead anomalies is in the upper part of the Penkiln Burn drainage basin and plumbogummite and pyromorphite have been identified in several of these samples. These anomalies have been traced to base metal mineralisation within the Black Shale Belt at the head of the stream (Leake et al., in preparation) with gossan surface expression containing complex crustiform plumbogummite and beudanticite. Several smaller-scale anomalies probably of similar origin occur further to the south-west along strike and also in the upper parts of Caldons Burn and Pulnee Burn.

Contamination by metallic rubbish of domestic or farm origin is thought to account for lead anomalies near New Galloway, between Gatehouse of Fleet and Kirkcudbright, north-west of Gatehouse of Fleet and south-east of Loch Mannoch, since in these samples there are also relatively high levels of tin. Anomalous samples east of Gatehouse of Fleet may be indicative of vein mineralisation which has been recorded in the area.

Thorium (concentrate)

Concentrates with the highest levels of thorium (up to 220 ppm) occur in one drainage basin to the south-west of the Fleet granite and a significant amount of monazite has been identified with these samples. Other relatively thorium-rich concentrates which occur within and adjacent to the eastern margin of the Fleet granite are also relatively enriched in rare-earths but sphene is the only potential thorium host identified in a concentrate from the area. Other rare-earths rich minerals with a significant thorium content may also be present in view of the discovery of a weakly radioactive pegmatite in the area (Tandy, 1974). The thorium-rich sample from east of Gatehouse of Fleet is also relatively cerium rich but the three other samples in the same concentration class, from Lowring Burn and from north-west of Gatehouse of Fleet, are relatively deficient in rare-earths.

Uranium (sediment)

Resampling of anomalous sites within the Fleet granite has shown that uranium contents of stream sediments vary

greatly with time. Duplicate samples from the base of Lowring Burn collected after 3 months and then after 3 years contained 15 ppm and 22 ppm respectively in contrast to the original level of 294 ppm. Though there is a measure of positive correlation between uranium and iron and manganese levels at sites which have been resampled, overall within both the stream sediments and fines samples (minus 240 BSI mesh) there is a lack of any significant positive correlation between these elements. This indicates that though uranium in the stream sediment is associated by absorption with the secondary oxide precipitate and clay fractions, in quantities influenced by the amount of rainfall and run-off prior to sampling, the anomalies reflect bedrock sources enriched in the element. In view of the lack of uranium enrichment in the concentrates corresponding to the anomalous sediment samples, the bedrock source is probably in the form of soluble secondary minerals in cracks, joints or along grain boundaries. No uranium mineralisation was found in a previous radiometric survey of the area (Tandy, 1974) but there are a few radiometric anomalies within the Fleet granite or its immediate aureole (maximum 100 μ R/h). Most of the radiometric anomalies found were in the margin of the pluton and associated either with quartz, muscovite veins with minor molybdenite or pegmatitic granitic veins in the immediate aureole. A boulder of moderately active pink granite was found in Lowring Burn well within the outcrop of the granite.

Uranium (concentrate)

Distribution patterns of uranium in concentrates are diffuse because of the low ratio between regional variance and combined sampling and analytical variance. Agreement between concentrates and sieved sediments is poor because of predominant hydromorphic dispersion of the element. The relatively uranium-rich concentrate from south-east of the Fleet granite is also rich in thorium and rare-earths.

